NISAR L-SAR Digital Electronics Subsystem

A Multichannel Distributed Processing System with Synchronous Timing Control for Digital Beam Forming and Multiple Echo Tracking

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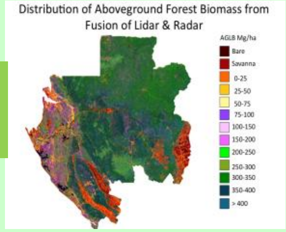
December 11, 2017

Mission Overview

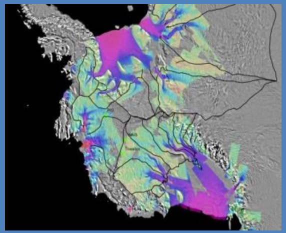
Mission Science

Ecosystem Structure



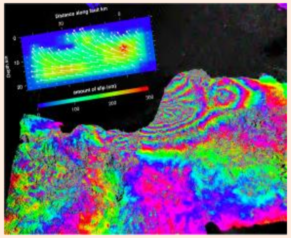
Biomass disturbance; effects of changing climate on habitats and CO_2

Cryosphere



Ice velocity, thickness; response of ice sheets to climate change and sea level rise

Solid Earth



Surface deformation; geo-hazards; water resource management

- Directed mission within the Earth Systematic Missions Program under NASA Earth Science Division
- Category 2 project (NPR 7120.5E) and Payload risk class C (NPR 8705.4)
- Major international partner: Indian Space Research Organization (ISRO) who is supplying the launch vehicle, S/C, and S-band radar
- Baseline launch date: No earlier than December 2020 (T-5 years)
- Dual frequency L- and S-band Synthetic Aperture Radar (SAR)
  - L-band SAR from NASA and S-band SAR from ISRO
- Sweep SAR technique (large swath) for global data collection
- Baseline orbit: 747 km altitude circular, 98 degrees inclination, sun-synchronous, dawn-dusk (6 PM–6 AM), 12-day repeat
- Repeat orbit within ± 250 m
- Spacecraft: ISRO I3K (flown at least 9 times)
- Launch vehicle: ISRO Geosynchronous Satellite Launch Vehicle (GSLV) Mark-II (4-m fairing)
- 3 years science operations (5 years consumables)
- All science data (L- and S-band) will be made available free and open, consistent with the long-standing NASA Earth Science open data policy

Science Objectives and Priority

Key Scientific Objectives

- Understand the response of ice sheets to climate change and the interaction of sea ice and climate
- Understand the dynamics of carbon storage and uptake in wooded, agricultural, wetland, and permafrost systems
- Determine the likelihood of earthquakes, volcanic eruptions, and landslides

Key Applications Objectives

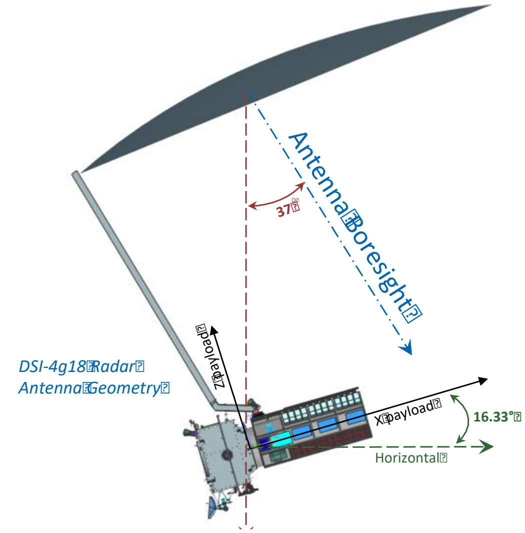
- Understand societal impacts of dynamics of water, hydrocarbon, and sequestered CO_2 reservoirs
- Provide agricultural monitoring capability in support of food security objectives
- Apply NISAR's unique data set to explore the potentials for urgent response and hazard mitigation

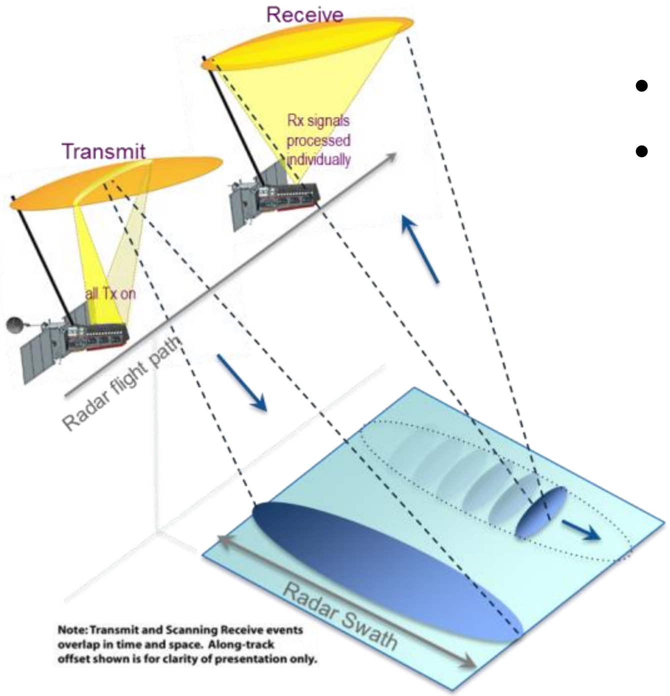
Priorities

- Three principal science objectives listed above have balanced priorities within the NASA program, as determined by Science Definition Team
- Over India, applications objectives are of prime importance

Instrument Overview

- Side looking L-band Synthetic Aperture Radar
- Fully polarimetric for classification and Biomass
- Repeat pass interferometer for deformation
- Split Spectrum for Ionosphere mitigation
- Multi-beam Array fed Reflector to achieve a 240 km swath
- PRF Dithering to fill transmit interference gaps
- Seamless mode transitions to minimize data loss

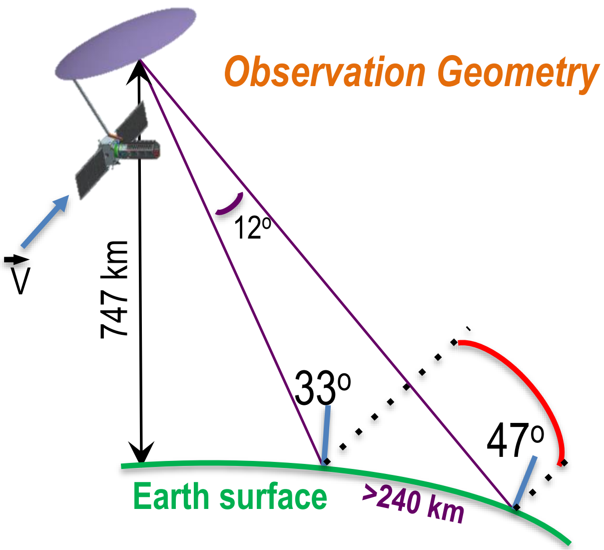


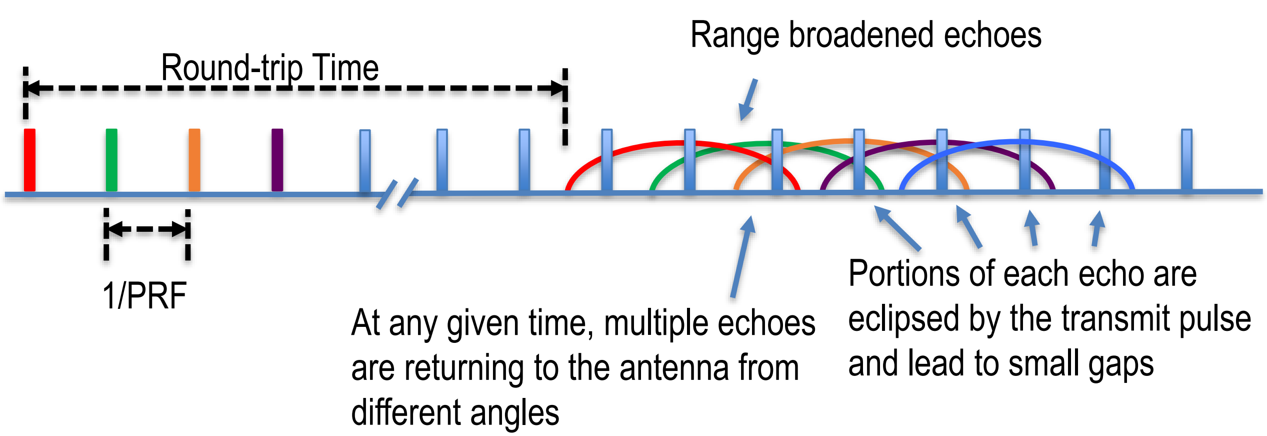


- On-board filtering and compression to reduce downlink
- SweepSAR timing and Digital Beam Forming to reduce ambiguities and preserve resolution / looks
  - On Transmit, illuminate the entire swath of interest
  - On Receive, steer the beam to follow the angle of the echo coming back to maximize the SNR of the signal and reject range ambiguities
  - Allow echo to span more than 1 IPP
  - 4 echoes are simultaneously returning to the radar from 4 different angles in 4 different groups of antenna beams

Complications of Observing a Wide Swath

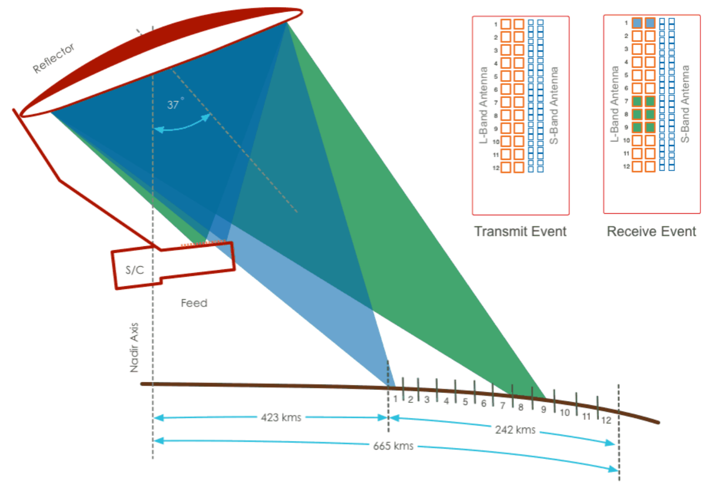
- To achieve the desired coverage and frequency of observation, the NISAR L-band radar is required to have a swath width greater than >240k m for a 12 day repeat.
- Antenna length (12 meter) and S/C velocity (7.5 km/s in low Earth orbit) set the minimum acceptable pulse repetition frequency (PRF)
- Antenna gain, transmit power and backscatter strength limit maximum altitude
- With these constraints, the time required to receive a single echo can exceed the time between transmit pulses by over a factor of 3
- To resolve the echoes from multiple pulses, the L-SAR Instrument has adopted the SweepSAR technique

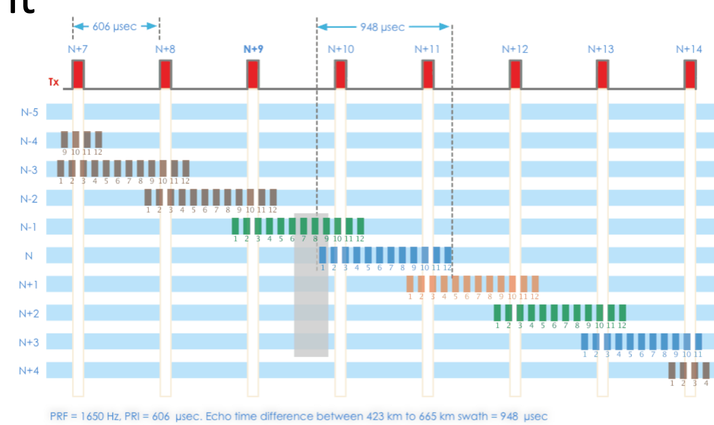




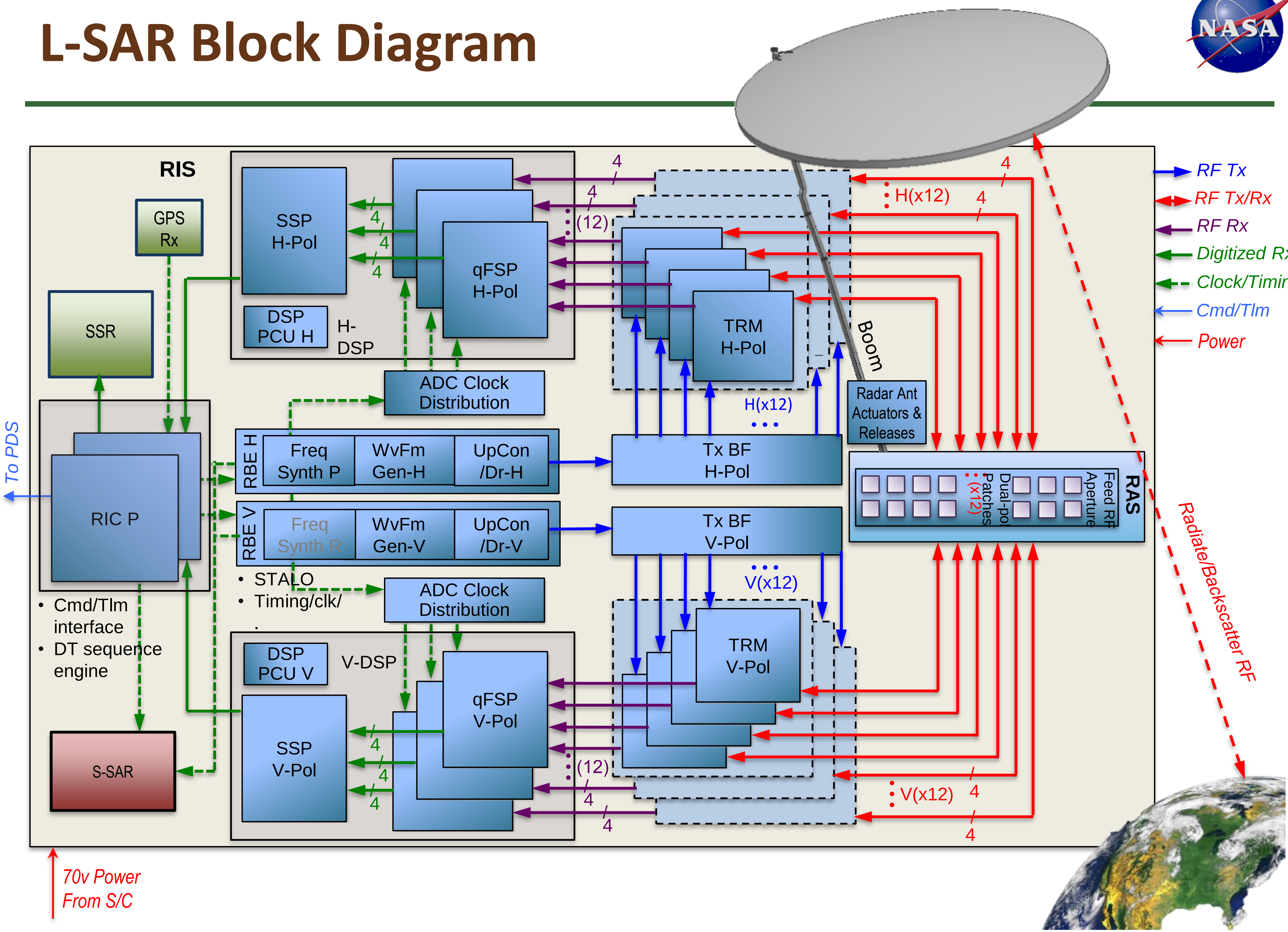
Wide Swath Coverage Achieved using SweepSAR

- The Basics
  - On Transmit, illuminate the entire swath of interest
  - On Receive, steer the beam in fast time to follow the angle of the echo coming back to maximize the SNR of the signal and reject range ambiguities
  - Allow echo to span more than 1 IPP
- Consequences
  - 4 echoes can be simultaneously returning to the radar from 4 different angles in 4 different groups of antenna beams
  - Each echo needs to be sampled, filtered, Beam-formed, further filtered, and compressed
  - On-Board processing is not reversible – Requires on-board calibration before data is combined to achieve optimum performance

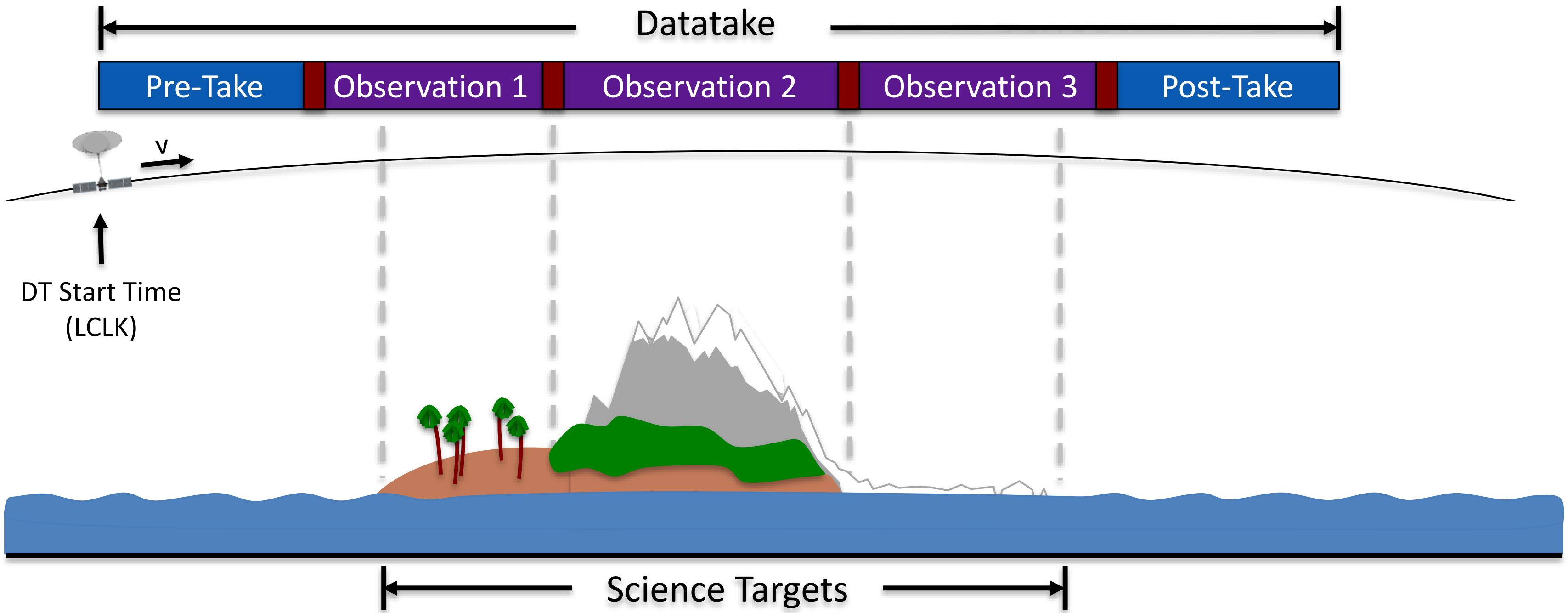




L-SAR Block Diagram

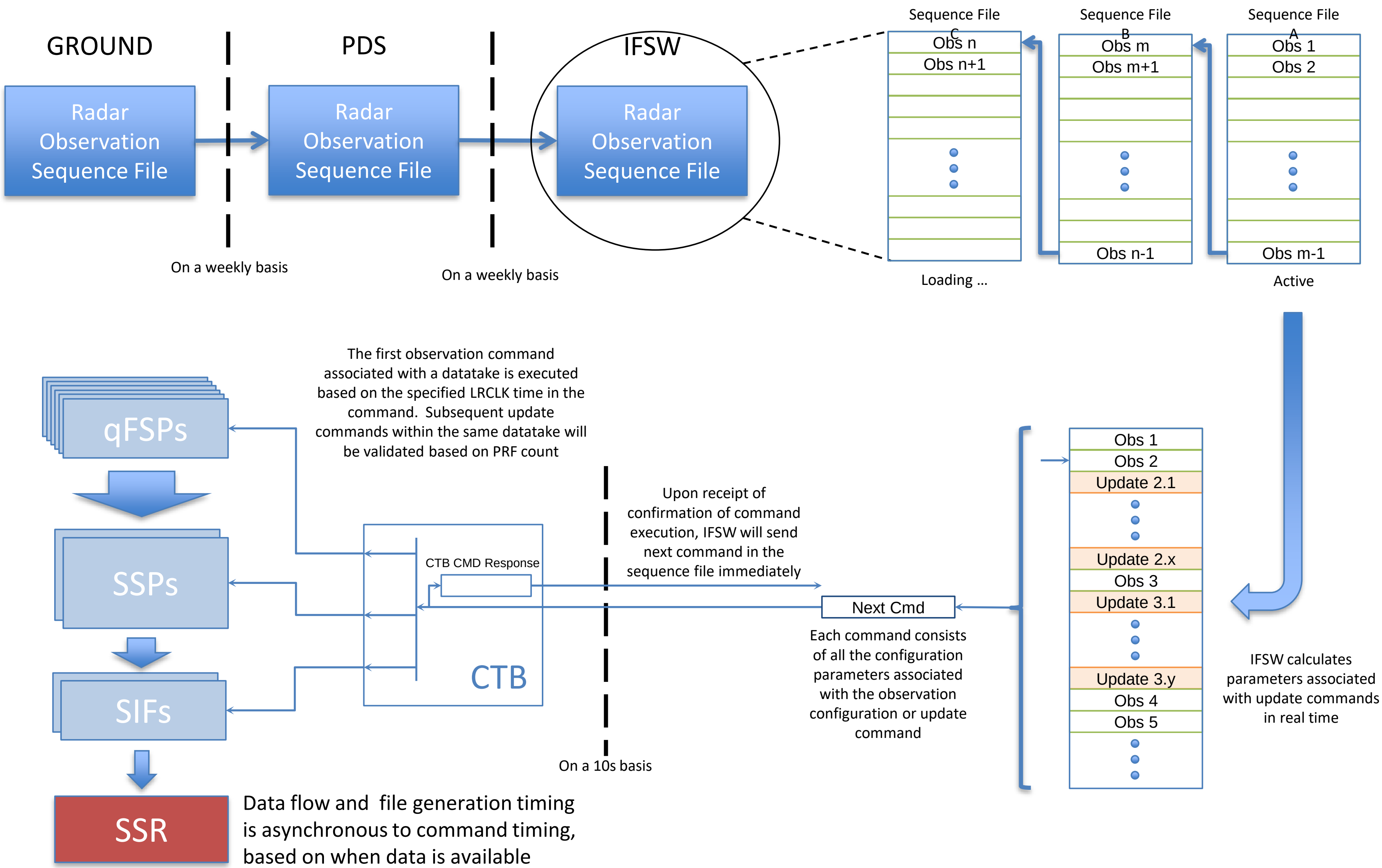


Radar Data Collection Overview



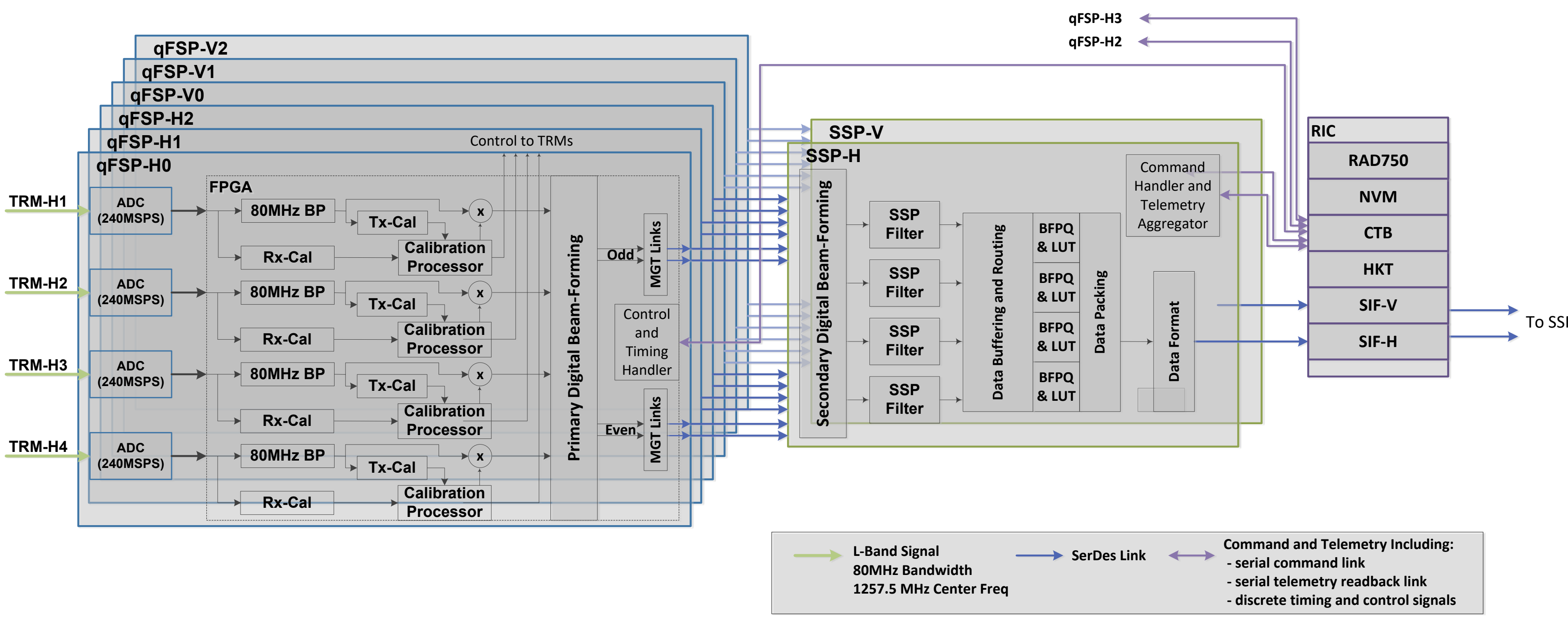
- The radar swath will frequently cross multiple science targets requiring different radar modes of operation
- The L-SAR radar is designed to transition seamlessly between mode combinations with no loss to science data at the mode changes
- L-SAR pulse count set to 1 at DT Start, increments uniformly throughout the entire datatake
- Minimum duration of any science observation is 2 seconds (L-SAR Synth aperture time: 2.7s)
- Pre- and Post-Take data are only collected at the very begin and end of the sequence of observations

NISAR L-band Instrument Data Collection Commanding



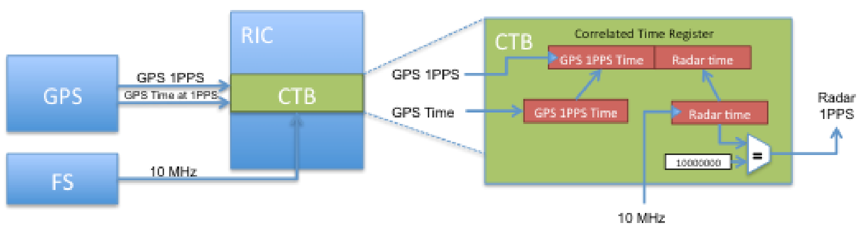
DSP Overview

- Digital signal processing techniques implemented in 3 stages compress science data to a format and data rate that meets requirements and telecomm subsystem constraints
- Processing includes Receive Digital Beamforming, Digital Filtering, and Calibration
- Programmable built-in calibration modes allow for radar performance optimization



Overall Timing Strategy

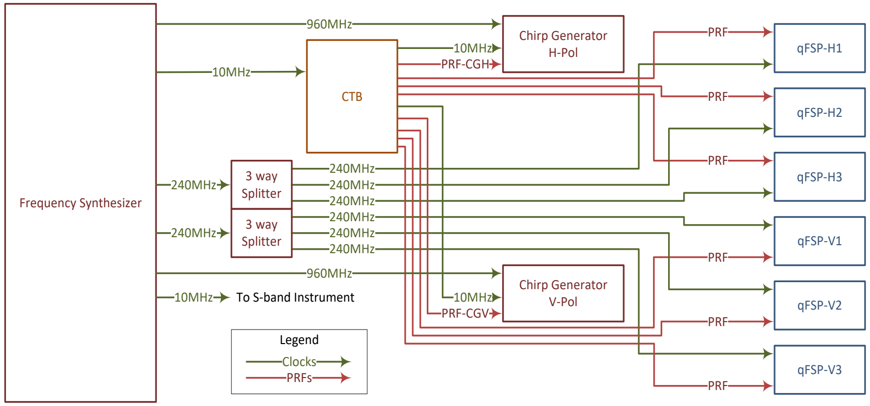
- The CTB will keep a 10MHz counter called the LRCLK that will serve as the master instrument clock
  - The LRCLK will be reset once at the beginning of the mission and maintained as a constant radar time base
  - All radar timing events will be uniquely time-tagged with an LRCLK value
  - The LRCLK will be correlated with GPS Time to provide knowledge of the relationship between the radar time paradigm and an external time reference



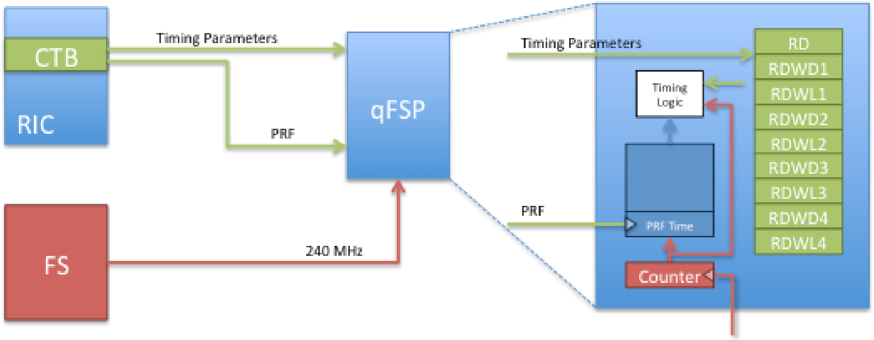
- During datatake operations the Radar Timing Reference (RTR) and its derivative signals are distributed throughout the system for timing and synchronization
  - Receive timing is referenced to the PRF signal that triggered the transmit of the signal being received

Timing Signal Distribution

- The PRF signal is a delayed version of RTR and distributed throughout the subsystem as shown to the right
- System synchronization is achieved by using the PRF as the master timing signal
- Requirements on accuracy and stability on the PRF and clock signals guarantee timing performance
- Commandable parameters are utilized to adjust all other relative timings
- Commandable parameters are also used to control the on-board processing including digital beam forming



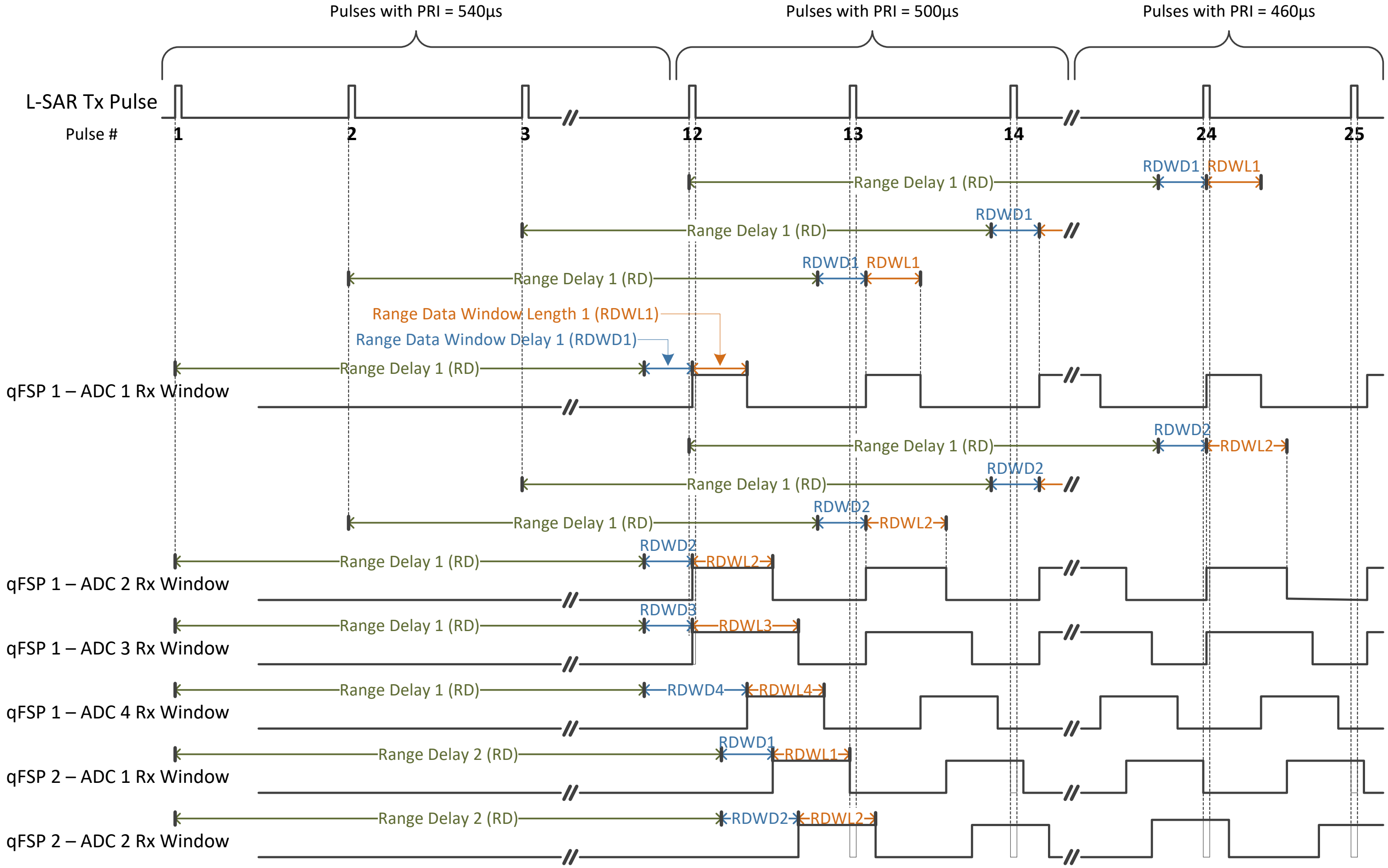
PRF and Clock Distribution



Channel Receive Window Timing Distribution

Receive Timing Windows

- Receiving timing windows are controlled by the PRF signal, which acts as the master timing signal for each TX/RX pulse pair
- Relative channel window timings are controlled via commandable parameters



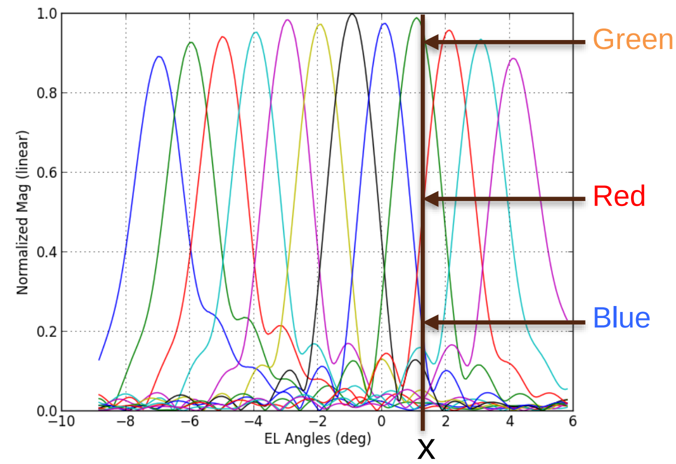
Note: Receive Window Timing for remaining 6 ADC Channels continues in the same pattern as laid out by first 6 shown

Digital Beam Forming

- Because the patterns of adjacent beams overlap, DBF is able to combine energy from these beams to improve and consolidate the signal into a single Composite Range Line (CRL)

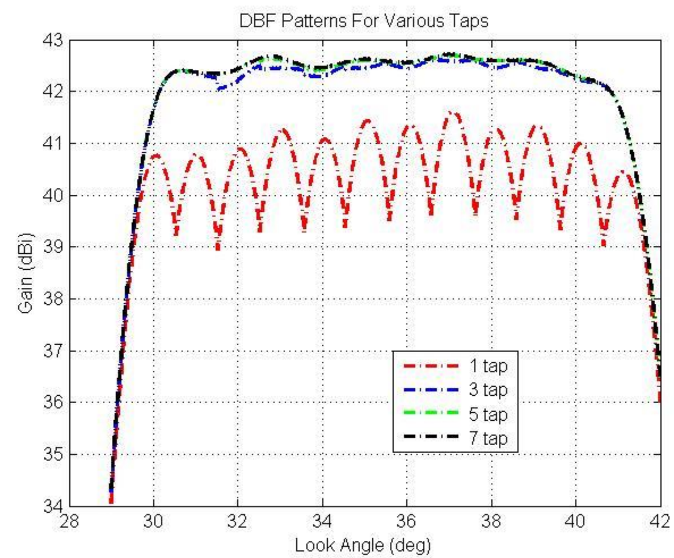
- The larger the overlap, the larger the benefit from combining more beams. Benefits can include higher SNR and lower ripple across range. As the number of beams increases, however, the percentage improvement gets smaller and smaller, and the implementation complexity goes up significantly

- Based on the resulting antenna pattern configuration, the L-SAR Instrument has selected a 3 tap beamformer for use on NISAR because it balances the performance benefits with the implementation complexity

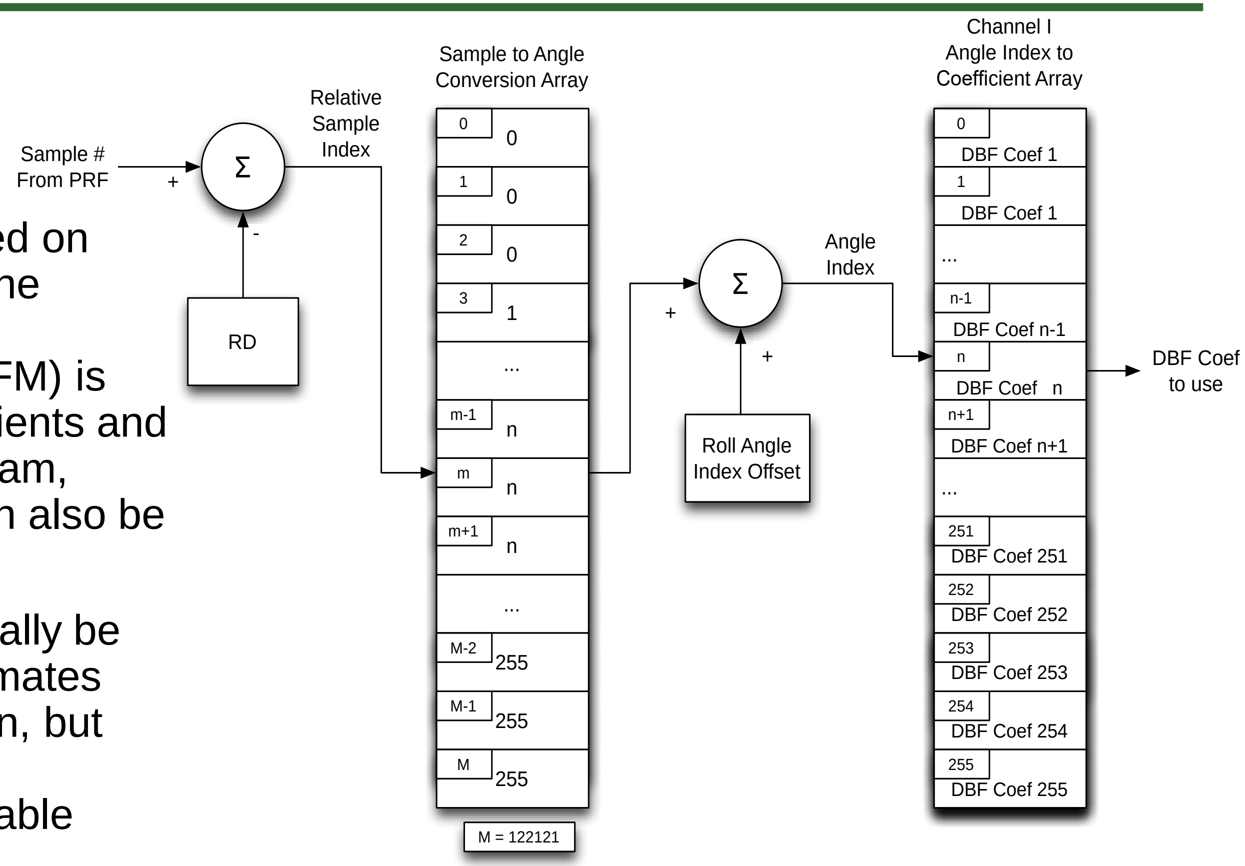


A target at angle x in the swath appears highest in Green.

Data from the beams on either side are also be used

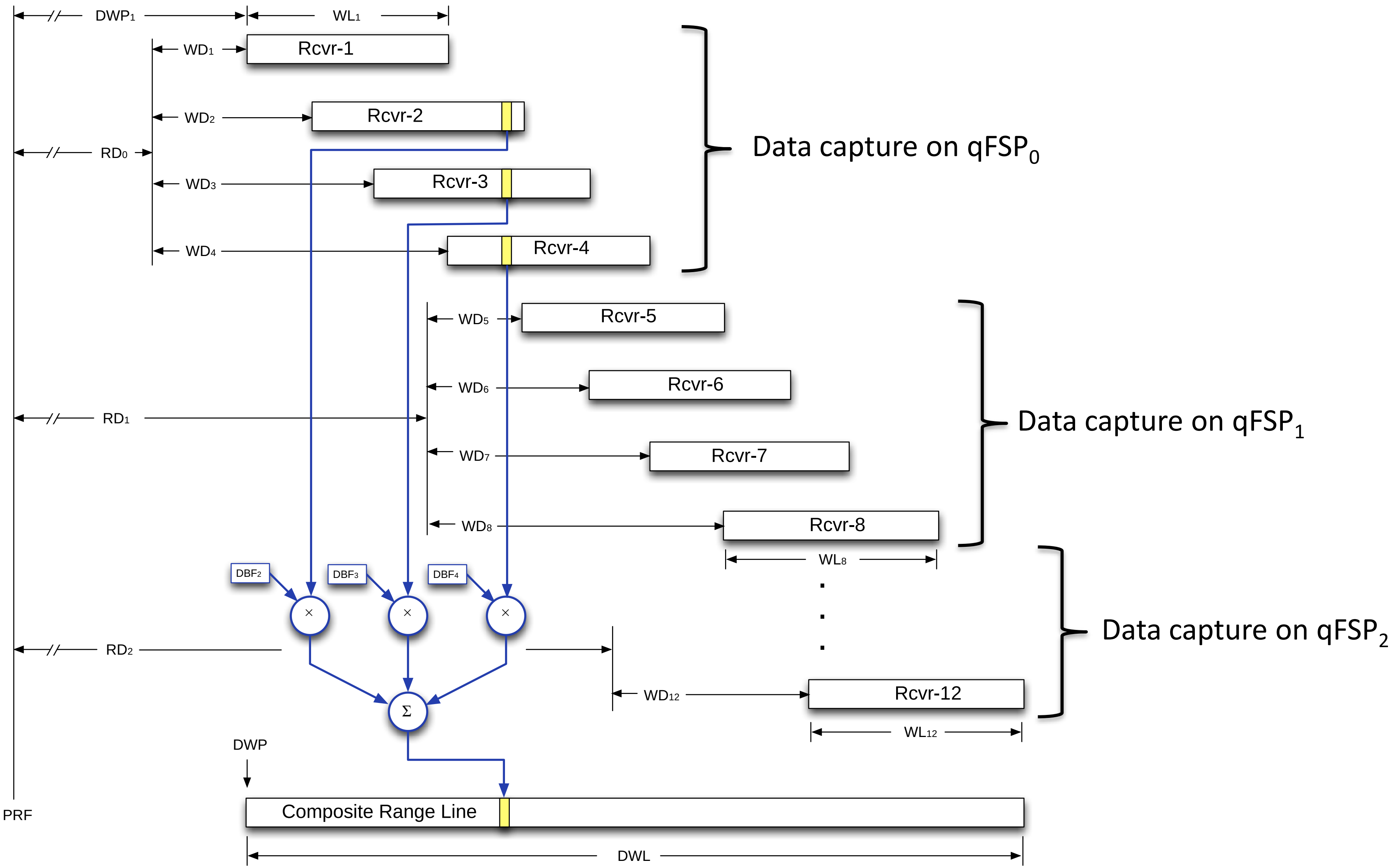


Digital Beam Forming



- DBF coefficients are computed on the ground and uploaded to the instrument via a DBF table. Conjugate Field Matching (CFM) is used to determine the coefficients and maximize SNR across the beam, however other techniques can also be used
- The DBF Coefficients will initially be based on the pre-launch estimates of the far-field antenna pattern, but will be updated as on-orbit measurements become available
- The angular resolution of the table is set by the angular span of the table and the number of entries which has been set at 256. With a total usable angle of about 12 degrees, and a desire from the hardware team to have a common angle range for the 4 channels within a qFSP, the resolution will be approximately 0.03 degrees, significantly better than the modeling uncertainty
- Each qFSP is loaded with the DBF table associated with the channels it controls

Digital Beam Forming



Summary

- The NISAR Digital Electronics Subsystem is a fully developed digital system implementing the SweepSAR technique to achieve high resolution wide-swath
- The Engineering Models of all the units in the subsystem have been built and are being tested
- Significant testing including firmware algorithms and hardware unit level testing have been completed
- Integrated system testing is on-going
- Key system attributes such as control, timing, commanding and telemetry reporting to ensure the proper operation of the system has been tested at various levels of integration